



Metalized MIC Substrates Using High K Dielectric Resonator Materials*

Hiroshi Tamura,
Toshio Nishikawa
and
Kikuo Wakino
Murata Manufacturing Co. Ltd.
Kyoto, Japan

Takuji Sudo
and
Murata Erie North America Inc.
State College, PA

Introduction

There are four basic circuit constructions for microwave communications systems that are either in use or under development: the mounting of discrete devices on PC boards, thick-film MICs, thin-film MICs and monolithic microwave integrated circuits (MMICs). Of these, PC board circuits have the advantage of low cost but the disadvantage of requiring the largest volume of the four types. Thick-film MICs using alumina substrates can miniaturize circuits, but they lack precise pattern control. Thus the thin-film MICs are used for industrial applications since they can satisfy the demands for high reliability, precise patterning and good producibility. Although MMICs are useful for mini-

aturization and have high reliability and low dissipation power, they have not been put into practical use because of their high cost.

We describe in this paper newly developed metalized substrates using high permittivity dielectric resonator materials. Their pore sizes were reduced to $2\text{ }\mu\text{m}$ average and $5\text{ }\mu\text{m}$ maximum so that they could be covered with high resolution circuit patterns. Compared with thin-film alumina substrates, they have the following advantages and disadvantages. The advantages are as follows:

- Since they have higher dielectric constants, circuits utilizing electric length elements (such as stubs or filters) are miniaturized.

- Since they have a temperature coefficient of $0\text{ ppm}/^\circ\text{C}$, temperature-stable microstrip line filters can be constructed directly on the substrate.

The disadvantages are as follows:

- Thermal conductivity of these materials is 10 times smaller than that of alumina.
- They have flexural strength 50 to 70 percent that of alumina.
- They are expensive since they need surface polishing.

Other characteristics (such as surface roughness, pore size and distribution, tensile strength between substrate and metalized electrode, and thickness of metalization) are

invited paper.

Property	Value
Dielectric constant	20
Dielectric loss tangent	0.001
Thermal conductivity	10 W/mK
Flexural strength	200 MPa
Thermal expansion coefficient	5 ppm/°C
Thermal stability	1000°C
Thermal shock resistance	1000°C
Thermal conductivity	10 W/mK
Flexural strength	200 MPa

comparable to those of alumina substrates.

The technique used to join the metalized substrate to the metal case and reliability test results also are reported in this paper, together with an example of a filter application.

Properties of High K Materials

Two kinds of high K materials, K=38 and K=88, were used for substrates.¹ Their electrical and physical properties are shown in comparison with high purity Al_2O_3 ceramics in Table 1. The Q values of these dielectrics theoretically follow

the following equation at microwave frequencies:²

$$Q_D \times f = \text{constant}$$

where $Q_D = 1/\tan\delta$, $\tan\delta$ is the dielectric loss and f is the frequency.

The Q_D shown in Table 1 is the experimental value measured by Hakki and Coleman's dielectric resonator method.³ Density and flexural strength are the values measured by using substrates 50 x 5 x 0.1 mm in size.

Surface Finish of High K Substrates

In order to reduce pore size and the number of pores, the substrates were made by a sheeting method using a doctor blade instead of the powder pressing method.

Figure 1 shows photographs of the polished surfaces. These photographs were analyzed using an image analysis system (Pias Co.'s model LA-555). The pore distribution in the surface area of 25,000 μm^2 for each sample was analyzed and the results are shown in Table 2. For a K=38 substrate, both the equivalent pore diameters and the number of pores were reduced greatly by the sheeting method. For the K=88 substrate, only the number of pores was reduced. Pore size was not noticeably reduced, as it was fairly small even by the pressing method. Being accompanied by the reduction of the number of pores the sheeting method improved the sintering density of the K=38 substrate from 5.14 to 5.25 g/cm³ and

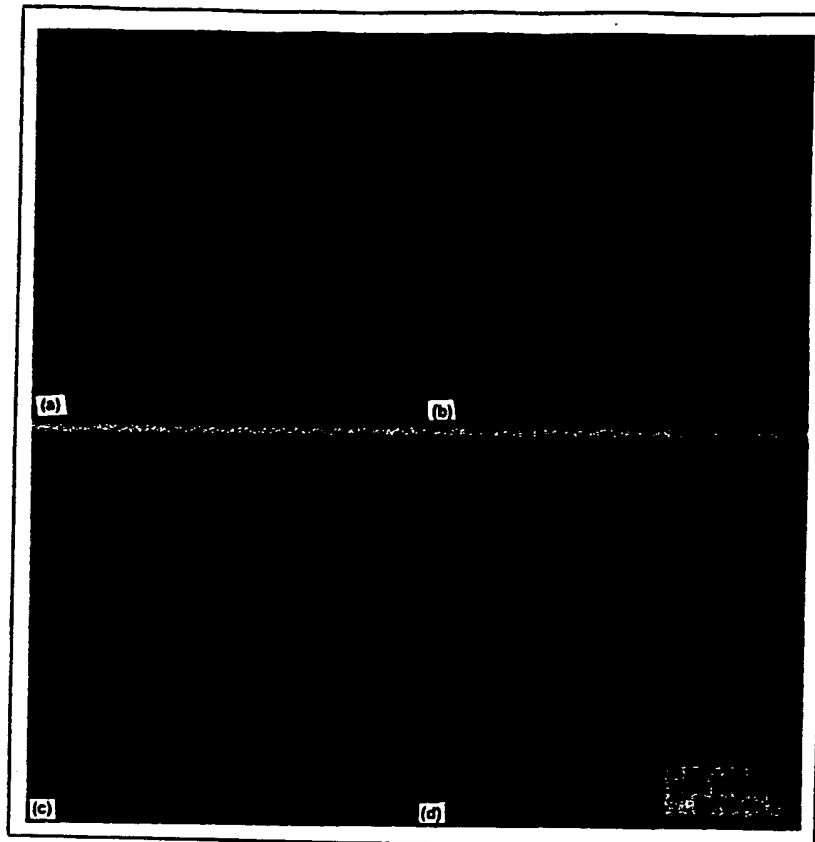


Fig. 1 Photographs of polished surfaces: (a) (Zr,Sn) TiO_4 , K=38, powder pressing method and (b) sheeting method; (c) $\text{BaO-PbO-Nd}_2\text{O}_3\text{-TiO}_2$, K=88, powder pressing method; and (d) sheeting method.

(Continued on page 120)

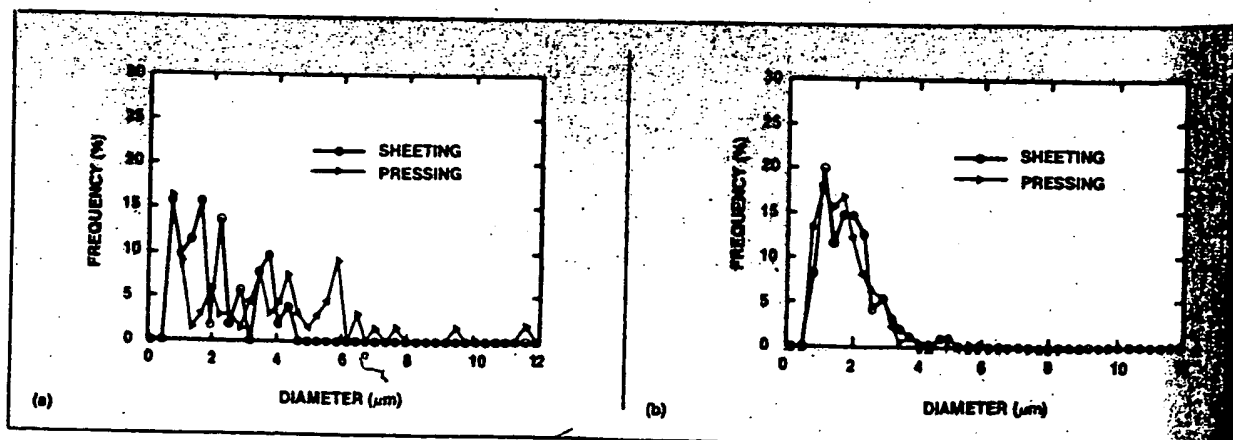


Fig. 2 Pore distributions of high K substrates: (a) (Zr,Sn) TiO_4 and (b) $\text{BaO-PbO-Nd}_2\text{O}_3\text{-TiO}_2$.

of the K=88 substrate from 5.78 to 5.82 g/cm³.

Figure 2 shows the pore distributions for these samples. It can be seen easily that the pores larger than 5 μ m diminish by using the sheeting method on the K=38 substrate, and that the pore distribution remains the same for the K=88 substrate. The resultant pore diameters are about 2 μ m (average) and 5 μ m (max.) for both the K=38 and K=88

substrates. Since the surface roughness of these substrates is larger than 0.2 μ m (R_a) or 2 μ m (R_{max}) on the as-fired surface, they need to be polished for use in thin-film MICs. Their polished surface roughness is shown in Figure 3. The roughness of $R_a=0.01 \mu$ m or $R_{max}=0.09 \mu$ m is comparable to that of the as-fired smooth alumina substrates and is well-suited for thin-film metalized substrates.

Metalization

On the polished substrates, an underlayer of 300 Å of NiCr is deposited by the vacuum evaporation technique. The substrates then are plated with Au or Cu; the thickness of the electrodes is selected from 1 to 5 μ m depending on the selected frequencies of operation.

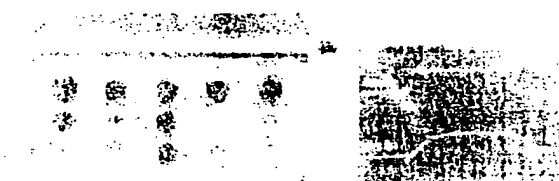
Other characteristics of metalized substrates are shown in Table 3. The

(Continued on page 122)

TABLE II
PORE DISTRIBUTION ON SURFACES OF HIGH K SUBSTRATES

Material	Parameter	Powder Pressing Method	Sheeting Method
(Zr,Ba) TiO ₃ (K=38)	Average pore diameter (μ m)	3.5	2.1
	Maximum pore diameter (μ m)	11.8	4.4
	Pore area ratio (%)	4.7	0.8
	Number of pores (pcs/mm ²)	3500	1900
BaO-PbO-Nd ₂ O ₃ -TiO ₂ (K=88)	Average pore diameter (μ m)	1.7	1.8
	Maximum pore diameter (μ m)	5.8	5.1
	Pore area ratio (%)	3.7	2.1
	Number of pores (pcs/mm ²)	13,800	8100

0.3 TO 2 NSEC VARIABLE RISE TIME PULSE GENERATORS AVMM SERIES



- PRF TO 25 MHz, PW VARIABLE 1.0 TO 10 NSEC
- 0 TO 5 VOLTS OUT, DC OFFSET AVAILABLE
- OTHER AVTECH PULSERS GIVE 40 PSEC RISE TIMES, 500 VOLTS OUT, PW FROM 0.2 NSEC TO 100 USEC AND PRF TO 300 MHz FOR GHz LOGIC, SWITCHING, OPTICAL COMMUNICATIONS, ATE, NUCLEAR AND OTHER APPLICATIONS
- 150 OTHER PULSE GENERATORS, PULSE AMPLIFIERS, IMPULSE GENERATORS, SAMPLERS, DELAY GENERATORS, TRANSFORMERS, POWER SPLITTERS, BIAS TEES, AND SCOPE PROBES LISTED IN OUR FREE 80 PAGE CATALOG

AVTECH
PULSED SYSTEMS
CORPORATION

PO. Box 1220 8th St.
Cranston, Canada - 02904
(610) 825-5772
Telex 053-4591
Fax: (610) 825-5772

U.S. CITIZENSHIP REQUIRED.
An Equal Opportunity Employer, M/F/H/V.

Impact the Future

Bell Aerospace currently has these career challenges available at its Niagara Falls Headquarters:

- **RF Design Engineer** — BSEE and two years' experience in digital design, signal processing, and communication systems.
- **Antenna Design Engineer** — MSEE and solid background in electromagnetics, microwaves, and phased array antenna design.
- **Antenna Design Engineer** — MSEE and solid skill in design and testing of microwave components (polarizers, waveguides, etc.) and reflective antenna experience.

Impact your future. For prompt, confidential consideration rush your resume, including salary history, to:

Stephen B. Colan
Professional Recruiter
ATN-91
Bell Aerospace TEXTRON
Post Office Box One
Buffalo, NY 14240

U.S. CITIZENSHIP REQUIRED.
An Equal Opportunity Employer, M/F/H/V.

Bell Aerospace TEXTRON

Division of Textron Inc.

Engineering Systems For Tomorrow.

[From page 120] TAMURA

tensile strength between substrate and electrode is 2 kg/mm^2 (average) and 1 kg/mm^2 (min.). The surface conductivities were measured by the dielectric rod resonator method described in reference 3. These conductivities have values of about 95 percent of the theoretical values of gold and copper. The tensile strength and surface conductivities are comparable to those of metalized alumina substrates.

The circuit patterns on the substrates are defined by photolithography. A mixture of iodine and potassium iodide solution may be used for etching.

Reliability

The life test of tensile strength and electric characteristics was performed on the substrates metalized with gold. The two test environmental conditions were temperatures of 85°C and 25 percent relative humidity, and 85°C and 85 percent relative humidity.

Figure 4 shows the results of the tensile strength life test. The data for 400 hours aging are now being obtained. We found that no significant deterioration of the tensile strength had occurred. Figure 5 shows the test samples for the data regarding aging of electric characteristics. The substrates were metalized with gold, and the half-wavelength microstrip line resonators with coupling capacitances were formed on them by using photolithographic techniques. The result is shown in

Table 4. The resonant frequencies of the samples were 2 GHz. The deviations of resonant frequencies and unloaded Q values after 1,000 hours of environmental test were found to be less than the measuring error level, showing that high reliability can be achieved by these high K metalized substrates.

Application

Since the effective dielectric constants of these substrates are four to 10 times higher than those of alumina substrates, we can reduce the circuit size by a factor of two or three by using these substrates. Microwave circuits such as filters or os-

[Continued on page 124]

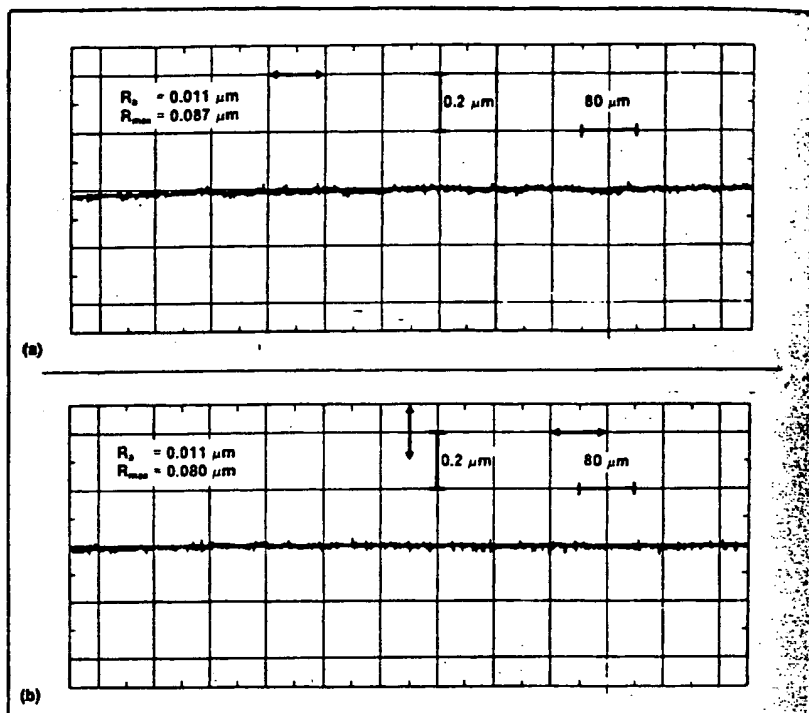


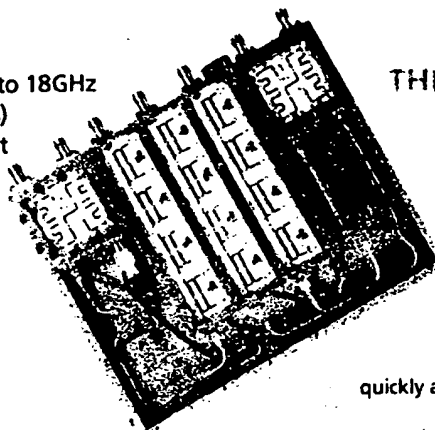
Fig. 3 Surface roughness of polished high K substrates: (a) $(\text{Zr,Sn})\text{TiO}_4$, $K=38$; and (b) $\text{BaO-PbO-Nd}_2\text{O}_3\text{-TiO}_2$, $K=88$.

PIN DIODE PHASE SHIFTERS... FROM



OUR DESIGNS FEATURE:

- Center frequency from 300MHz to 18GHz
- Up to 6-bit resolution (5.6° steps)
- Up to octave bandwidth for 3-bit and 4-bit units
- More than 30dB carrier and sideband suppression (serrodyne)
- High-speed TTL control
- Stable alumina microstrip construction
- High reliability, 1500 units in service in ALQ-135 and ALQ-161



THE PHASE SHIFTER EXPERTS

VECTRONICS MICROWAVE CORPORATION for more than 15 years has been in the forefront of supplying microstrip PIN diode phase shifters and serrodyne translators. Our optimized designs meet the requirements of common air traffic control, radar, telemetry, communications and ECM bands. We are experts in converting special phase shifter requirements into practical designs quickly and economically, using proven technology.



VECTRONICS MICROWAVE CORPORATION

113 LINCOLN BOULEVARD, MIDDLESEX, N.J. 08846
(201) 356-2377 TELEX: 833560 FAX: (201) 356-6782

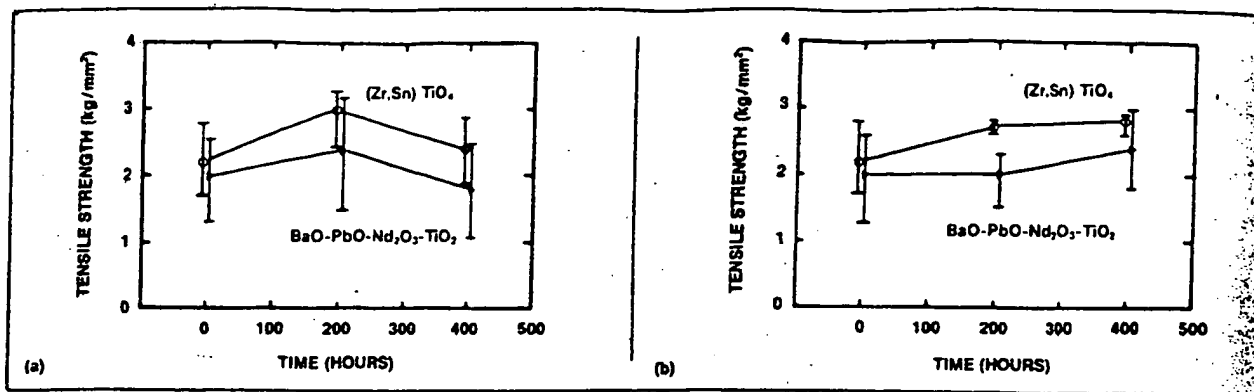


Fig. 4 Tensile strength after 400 hours of environmental test (n=5): (a) high temperature life test (85°C); and (b) humidity test (85°C, 85 percent relative humidity).

cillators can achieve good temperature stability since the temperature coefficient of these materials can be controlled to a level of 0 ppm/°C.

Figure 6 shows a photograph and characteristics of a 1 GHz-band bandpass filter for a direct broadcasting satellite (DBS) receiver. The interdigital filter consisting of seven microstrip line resonators was constructed by a photolithography technique. A material of K=88 was used for the substrate, and the chip size was reduced to 8 x 17 mm. The 12 GHz-band bandpass filter for a DBS converter, shown in Figure 8, was made in the same way. The

parallel coupled filter consists of four microstrip line resonators.

Because the flexural strength of the high K substrate material is lower than that of the alumina substrate, high K substrates cannot withstand the thermal stress resulting from the difference of the thermal expansion coefficients between substrate and metal base, particularly when they are soldered to a metal base. One solution to this problem is to use a conductive adhesive such as Murata's CP-3P, which consists of fine silver particles suspended in epoxy resin and which has a low resistivity of 10^{-4} ohm-cm and tensile strength

of 100 kg/cm².

Conclusion

We have developed metalized substrates using high K dielectric resonator materials. Their pore sizes were reduced to an average of 2 μ m and a maximum of 5 μ m. The substrates were polished to a surface roughness of 0.1 μ m and were metalized with Au or Cu. Although these high K substrates have the

[Continued on page 126]

TABLE III METALIZATION CHARACTERISTICS
Surface roughness: $R_a = 0.01 \mu\text{m}$, $R_{max} = 0.09 \mu\text{m}$
Underlayer: NiCr thickness = 300 Å
Overlayer: Au or Cu thickness = 1 to 5 μm
Tensile strength: $>1 \text{ kg/mm}^2$ (2 kg/mm^2 average)
Conductivity: $4.2 \text{ ohm}^{-1}\text{m}^{-1}$ for Au; $5.5 \text{ ohm}^{-1}\text{m}^{-1}$ for Cu

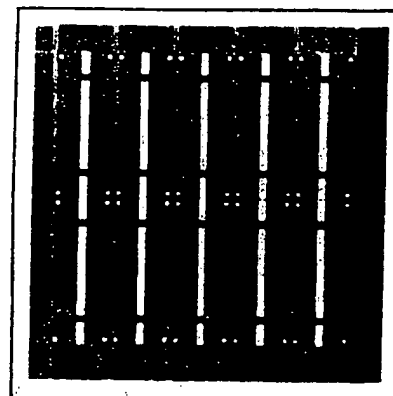


Fig. 5 Microstrip line resonators used for the life test of electric characteristics.

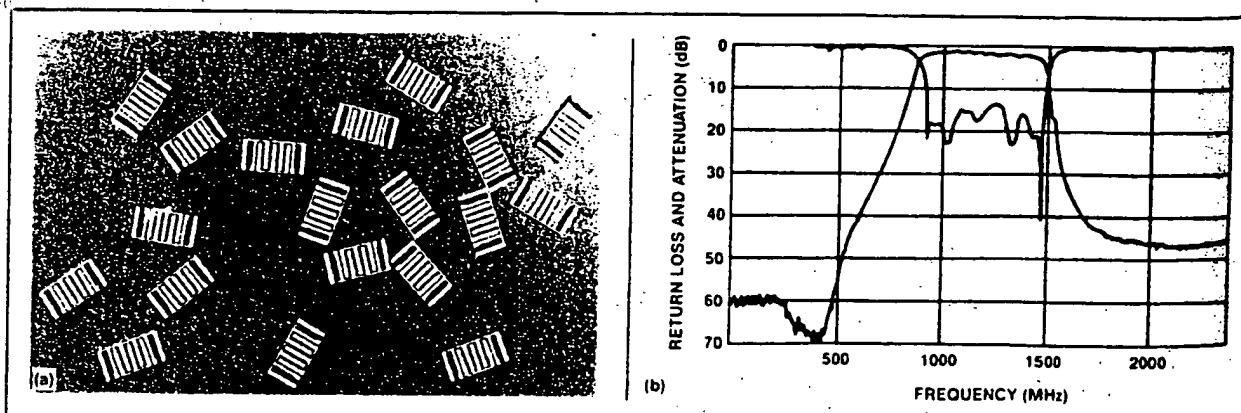


Fig. 6 (a) Photograph and (b) characteristics of a 1 GHz microstrip line filter.

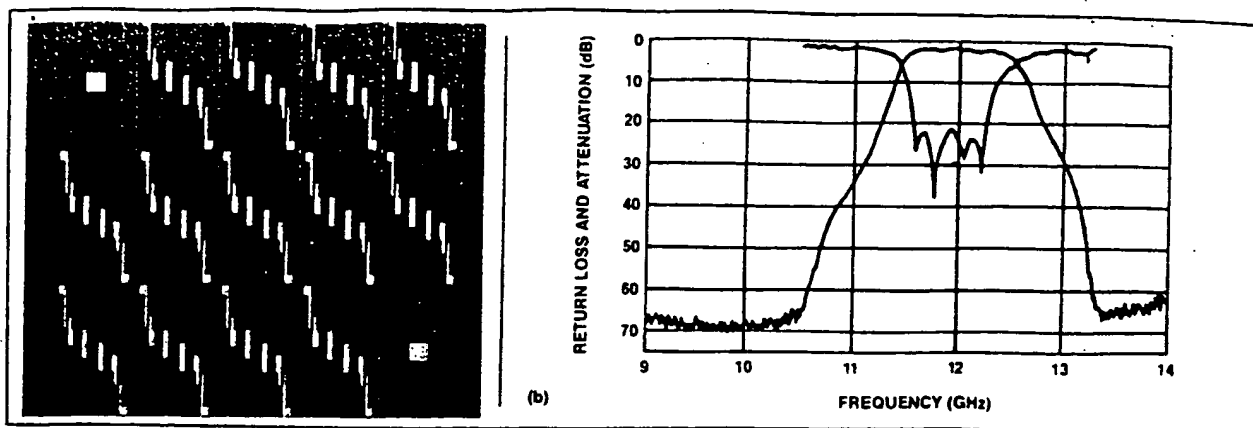


Fig. 7 (a) Photograph and (b) characteristics of a 12 GHz microstrip line filter.

TABLE IV DEVIATIONS AFTER 1000 HOURS OF ENVIRONMENTAL TEST			
Material	Type of Deviation	Deviation (%) at 85°C, 20% RH	Deviation (%) at 85°C, 85% RH
(Zr,Sn) TiO ₄	$\Delta I/I_0$	<0.01	<0.01
	$\Delta Q/Q_0$	<0.5	<0.5
BaO-PbO-Nd ₂ O ₃ -TiO ₂	$\Delta I/I_0$	<0.01	<0.01
	$\Delta Q/Q_0$	<1.0	<1.0
Initial Values: (Zr,Sn) TiO ₄ : $f_0=2321$ MHz, $Q_0=123$ BaO-PbO-Nd ₂ O ₃ -TiO ₂ : $f_0=1654$ MHz, $Q_0=79$			

disadvantage of lower flexural strength compared with alumina substrates, this disadvantage can be overcome by carefully choosing adhesives and mounting techniques. The high K substrate application is beginning to spread in the MIC field.

Acknowledgment

The authors would like to thank the following engineers at Murata Manufacturing Co. Ltd.: M. Saito, T. Fujita and K. Tanaka for their development of pore-reduced substrates; S. Sekimoto and Y. Yoshino for their development of metalization techniques; and H. Tanaka for his reliability test. ■

References

1. K. Wakino, K. Minai and H. Tamura, "Microwave Characteristics of (Zr, Sn) TiO₄ and BaO-PbO-Nd₂O₃-TiO₂ Dielectric Resonators," *J. Amer. Ceram. Soc.*, Vol. 67, 1984, pp. 278-281.
2. K. Wakino, T. Nishikawa, H. Tamura and T. Sudo, "Dielectric Resonator Materials and their Applications," *Microwave Journal*, June 1987, pp. 133-150.
3. Y. Kobayashi and M. Katoh, "Microwave

Measurement of Dielectric Properties of Low-Loss Materials by the Dielectric Rod Resonator Method," *IEEE Trans. on MTT*, Vol. MTT-33, 1985, pp. 586-592.

Hiroshi Tamura graduated from Kyoto University in 1973 with a BS in electrical engineering. He joined Murata Manufacturing Co. Ltd. in 1973 and has been contributing to the development of dielectric resonator materials. He is a member of the American Ceramic Society, the Japanese Ceramic Society and the IECEJ.



Toshio Nishikawa was born in Ishikawa, Japan in 1935. He received a BS degree in electrical engineering from Kanazawa University in 1958. Since joining Murata Manufacturing Co. Ltd. in 1961, he has been engaged in research and development of microwave filters using dielectric resonators. He is a member of the IEEE and IECEJ.



Kikuo Wakino graduated from Osaka University with a BS in physics in 1950 and joined Murata Manufacturing Co. Ltd. in 1952. He served as a leader in the development and engineering of electronic ceramics for ceramic capacitors, piezoelectric ceramic devices and microwave dielectric resonators. He received a PhD in engineering from Osaka University in 1980. Wakino is a member of the American Ceramic Society, Japanese Ceramic Society, Japanese Physical Society, Japanese Applied Physical Society and the American Physical Society, and he is a staff member of the Japan Society of Powder Metallurgy.



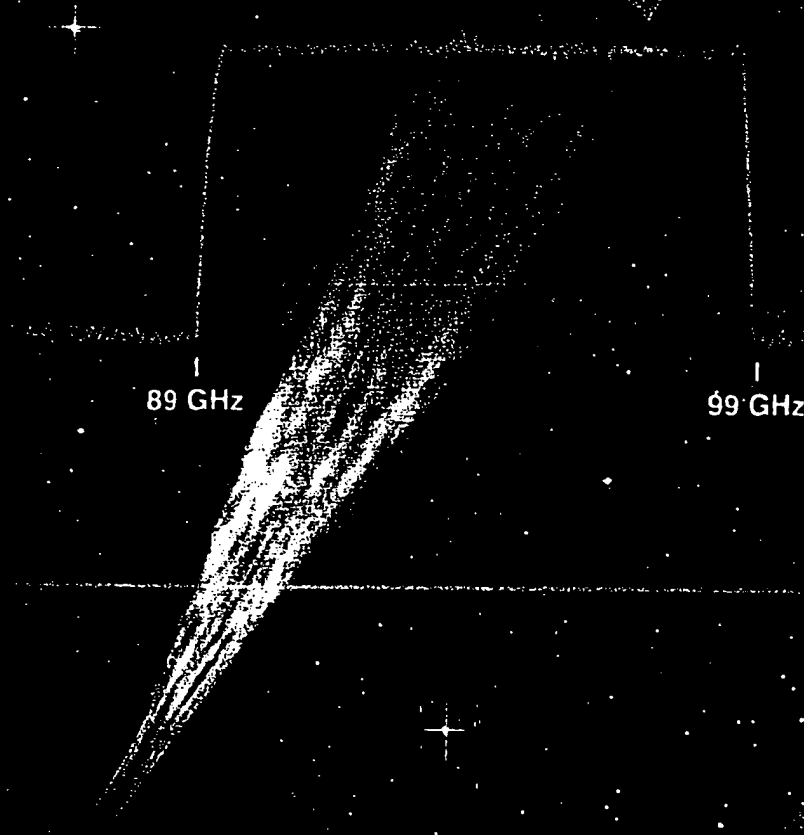
Takuji Sudo was born in Aomori, Japan in 1943. He received a BS degree in electrical engineering from the University of Electrocommunications in 1966. After obtaining diversified experience in communication systems design, he joined Murata Manufacturing Co. Ltd. in 1975 to combine high-tech ceramics with new market demands.





- Solid state amplifier special report
- Microwave characteristics of 77°K superconductors
- Measuring dielectric properties
- Thin film design guidelines

contents, p. 10



Horizontal Displacement

BEST AVAILABLE COPY

ports

UNQ

14

104

20

20

1-1

60.

353

30

Figure 1



microwave JOURNAL

VOL 31 NO 10

OCTOBER 1988



ON THE COVER

Watkins-Johnson's varactor-tuned Gunn oscillators offer new levels of output power and tuning bandwidth for W-band applications. Cover art concept by Patricia Cardoza; artwork by Dave Pauly; photography by Lee Miller. Cover art courtesy of Watkins-Johnson Co. Cover story begins on p. 137.

FEATURES

SPECIAL REPORT

Solid-State Amplifiers Pursue Higher Power Levels at Higher Frequencies

Howard Bierman, Contributing Editor

26

TECHNICAL/APPLICATIONS

Microwave Characteristics and Characterization of High T_c Superconductors

Aly Fathy, David Kalokitis and Erwin Belohoubek, David Sarnoff Research Center

75

Dielectric Resonances for Measuring Dielectric Properties
Gordon Kent, Dielectric Laboratories Inc.

99

Metalized MIC Substrates Using High K Dielectric Resonator Materials

Hiroshi Tamura, Toshio Nishikawa and Kikuo Wakino, Murata Manufacturing Co. Ltd., Kyoto, Japan and Takuji Sudo, Murata Erie North America Inc.

117

Thin-Film Design Guidelines for Microwave Circuitry
Michael D. Casper, MPC Inc.

129

DEPARTMENTS

Coming Events	13	Cover Story	137	Microwave Products	153
Sum Up	18	Catalog Update	143	Classified	160
Workshops & Courses	22	Product Features		New Literature	161
News From Washington	43	Alpha Industries	148	Ad Index	162
Int'l Marketplace	46-1*	Taconic Plastics	149	Sales Reps	162
International Report	49	Tektronix	150		
Commercial Market	55	Rogers Corp.	152		
Around the Circuit	60				

Press run for this issue is 53,191 copies.

*Euro-Global Edition only

Microwave Journal (USPS 396-250) (ISSN 0192-6225, International Edition; ISSN 0192-6217, Euro-Global Edition) is published monthly by Horizon House-Microwave, Inc. 685 Canton St., Norwood, MA 02062. Second class postage paid at Norwood, MA 02062 and additional mailing offices. This journal is issued without charge upon written request to qualified persons working in that part of the electronics industry including governmental and university installations that deal with VHF through light frequencies. Other subscription are: domestic one year, \$40, two-year subscriptions, \$70; foreign, \$50 per year, two-year subscriptions, \$90, back issues (if available) and single copies, \$5.00.

Copyright © 1988 by Horizon House-Microwave, Inc. Microfilm copies of Microwave Journal are available from University Microfilms, 300 N. Zeeb Rd., Ann Arbor, MI 48106.

POSTMASTER: send address corrections to Microwave Journal, 685 Canton Street, Norwood, MA 02062.



Horizon House also publishes
Telecommunications and
Journal of Electronic Defense

CONTENTS